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Assessment of forage availability in ecological studies

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Abstract In this study we describe and calibrate a quantitative index method to estimate leaf biomass and forage availability for browsers at different feeding heights. The method is based on an index relating leaf biomass to a number of leaf contacts with a vertical, three-dimensional (25×25×165 cm) metallic quadrat with a central rod and takes into account the characteristics of leaves (shape, size, and thickness) to define plant categories and then produce general allometric equations per category. We then discuss the use of this biomass index to evaluate the quality of habitats for browsers in terms of food resources.

Keywords Browse · Forage assessment method · Habitat quality · Herbivores · Leaf biomass · Temperate forest

Introduction

In forested habitat, wildlife managers increasingly need to rely on repeatable and easy indicators to assess the relationships between ungulates and their habitats (Kie et al. 2002; Saïd and Servanty in press). For example, the abundance of palatable browse species could be used as an indicator of habitat quality (Pettorelli et al. 2001). In temperate forests, roe deer populations are often limited by fawn survival, which is related to vegetation conditions in spring and summer (Gaillard et al. 1998). Leaves are among the most important spring and summer foods for deer species (Mautz 1978; Rogers and McRobert 1992; Duncan et al. 1998). However, it is difficult to determine the leaf biomass within reach of deer, especially in forest ecosystems with different body sized deer species, which eat foods of different resource quality and access different browse heights. Consequently, wildlife managers require adaptable tools to monitor the biomass of leaves (Warren 1997; Morellet et al. 2001). Many methods exist for evaluating woody plant biomass (Lyon 1968; Oldemeyer and Regelin 1980; Etienne 1989; Pitt and Schwab 1990). A general assumption is that there is a linear relationship between the measure used and actual plant biomass. The objective of these methods is to provide an index of biomass that can be used non-destructively once calibrated.

The most common technique to estimate available leaf biomass includes the clip and weight method (Schwan and Swift 1941). It is based on clipping and weighing a number of selected individuals within sample plots representative of the rangeland being estimated. Plot size, shape, and the number of samples frequently depend on the vegetation structure and type of shrubland (Feuillas 1979; Etienne 1989; Rogers and McRobert 1992).

Another method developed for estimating overall foliage density is the point-quadrat, with observations at one, two, and three angles (Warren-Wilson 1963). This method has the advantage of allowing the distinction between different types of stem-like organs (Philip 1966). An attempt to combine the point-quadrat and the clipping/weighing method was used to measure, (1) leaf canopy on deciduous woodland, (2) foliage amounts per height strata on Mediterranean coppice, and (3) to predict shrub biomass on arid lands (Joffre 1978). In this case, the method showed good correlations only between the number of contacts and the biomass for small shrubs

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(Joffre 1978). Unfortunately, equations were not presented, preventing their use for other sites.

In the context of a study on food resource availability and quality in browsers, we combined a contact method and a clipping/weighing method to quantify browse biomass availability at different height strata. The method uses a three-dimensional (3D)-quadrat instead of a single rod, that is, it produces a number of contacts per volume vs contacts on one rod. Here, we present the principles of the method and the equation we built from the relationships between our 'hit' index and the clipped biomass for several species and for different tree/shrub categories. We then discuss the relative advantages of our method in the context of studies on forest–ungulate relationships.

Materials and methods

Study area

The study was carried out in spring (May and June) in the *Réserve Nationale de la Chasse et de la Faune Sauvage* of Chizé, 2,614 ha of game-proof fenced forest in western France (46°05′N, 0°25′W). The climate is oceanic with Mediterranean influences and is characterised by mild winters and hot, dry summers. Forest productivity is low, probably because summer droughts are common (Gaillard et al. 1996). The soils are shallow and essentially calcareous under chalky soil in the northern part of the reserve (1,397 ha) and limestone soils or clay in the southern part (Lambertin 1992). The dominant trees are deciduous (*Quercus* spp., *Fagussylvatica* and *Carpinus betulus*).

To test the robustness of our method we tested the biomass index in another forest with similar species but with different habitat phenology and climatic conditions, the *Territoire d'Etude et d'Expérimentations* of Trois-Fontaines. This enclosed forest covers 1,360 ha in north-east France (48°43′N, 4°56′W) and has a continental climate characterised by cold winters and hot summers. The forest overstory is dominated by oak (*Quercus* spp.) and beech (*Fagus sylvatica*), the coppice by hornbeam (*C. betulus*). The soil is fertile and the forest highly productive as indicated by a long-term average of 5.92 m^3 of wood produced/ha/year (*Inventaire Forestier National*) (Widmer et al. 2004). The soil moisture in Trois-Fontaines is higher compared to Chizé.

Roe deer populations in both sites have been monitored by CMR studies since 1976 (Trois-Fontaines) and 1978 (Chizé) (Gaillard et al. 1993). Estimates obtained from this monitoring indicate that the population density did not vary during our study period at Chizé (2001: mean = 11.1/km^2 ; 2002: mean = 11.8/km^2 ; in Saïd and Servanty in press). We only measured biomass in 2003 at Trois-Fontaines when roe deer population density was 23.6/km^2.

The biomass index

Plant measures and biomass collection

The abundance and biomass of plants was determined using a vertical, 3D (25×25×165 cm) metallic quadrat with a central rod (Fig. 1). The 3D-quadrat can be partly dismantled for ease of application.

The biomass index is defined as the total number of contacts, 'hits', made by leaves on any of the five vertical metallic rods of our 3D-quadrat. To take into account the structural complexity and the vertical distribution of the leaf biomass, counts were made for each predefined height stratum (strata 1: 0–45 cm and strata 2: 45.1–85 cm and strata 3: 85.1–165 cm). We thus had 20 randomly placed replicates for each species considered.

For this study, we focus on 25 plant species in deciduous forest. A total of 396 plots (1 plot = 1 measure at one place with the 3D-quadrat) were made during spring (May and June) of 2001 and 2002 within the study area. They were divided between the 25 plant species. On each plot and for each stratum, the (total) number of hits for each plant species were counted. All plant parts contained within each strata of the

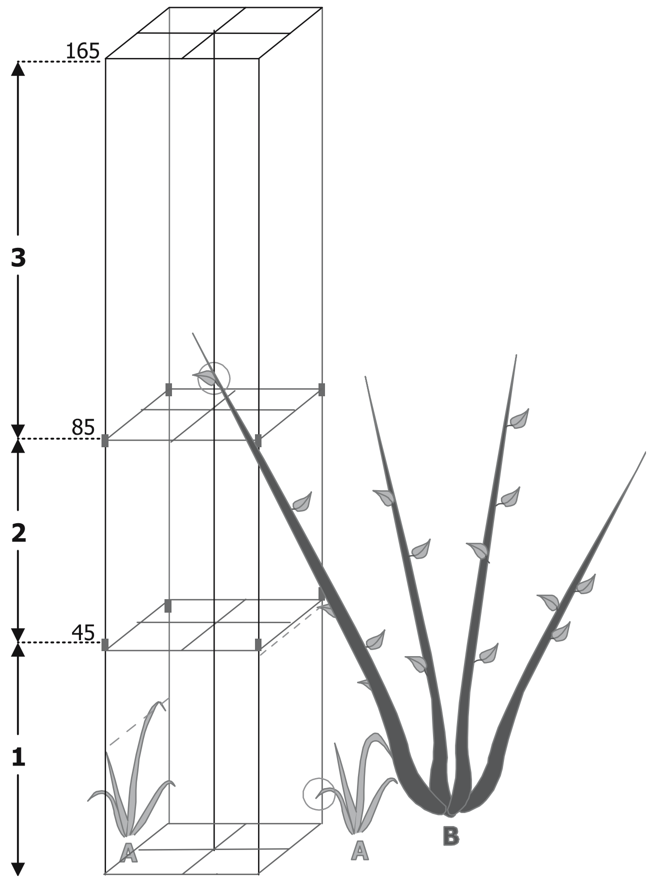


Fig. 1 Representation of 3D-quadrat with a central rod. We observed one contact between 0 and 25 cm (strata 1) for two plants *A* and one contact between 85.1 and 165 cm (strata 3) with 3D-quadrat for plant *B*

3D-quadrat were then carefully removed with pruning shears. All specimens of each species present on each sample plot were also cut. In the laboratory, plants were then divided into leaves and stems. The samples from each specimen were then oven-dried at 60°C for 48 h and weighed.

Building equations

We constructed equations relating the dried biomass to the number of hits per species, and per height stratum. All the edible organs, leaves, and flowers were clumped for each species, and dried to constant weight. For these equations, we grouped the leaves of rare tree species (i.e. small sample size) with those from a similar and more abundant species: for example, *Ulmus minor* (rare) was merged with *C. betulus* (abundant). For monocotyledons, species were not distinguished (Table 1).

Statistical analysis

The data were not normally distributed (Kolmogorov–Smirnov test: all $d < 0.305$, all P-values < 0.011), and were therefore square-root-transformed to achieve normality (Kolmogorov–Smirnov test: all $d > 0.185$, all P-values > 0.085) before conducting this analysis. After transformation we obtained normality for all species or group of species, except for the group of species we labelled 'others and *Euphorbia* spp.'. Linear regression analysis was based on the equation ($\sqrt{Y} = aX + b$ where Y is biomass and X is number of hits of the species in the 3D sampling frame).

All analyses were performed by using the software package Rgui, 1.6.1 (http://cran.r-project.org/).

Results and discussion

We first tested for difference in equation per height strata, and found a significant effect of strata for nine species (*C. betulus, U. minor, Cornus* spp., *Crataegus* sp., *Prunus* sp., *Fraxinus* sp., *Sorbus* sp., *Rosa* sp., *Quercus* spp.; all $F > 3.2158$, all $P < 0.010$). We reran the analyses to assess which strata differed, and found that for these four species it was strata 1–3 that had significantly different equations (all $F > 2.234$, all $P < 0.05$). Strata 2 did not differ from the other two. We decided to gather the 45–85 cm and the 85–165 cm strata because seedlings, located in the 0–45 cm strata, are morphologically distinguishable from taller plants (45 cm < height < 85 cm and height > 85 cm). In Trois-Fontaines, we also recorded three new species, for which we calculated the relationship between the number of 'hits' and the biomass: *Populus tremula*,*Betula* spp., and *Salix* spp. (Table 2).

For the others species, there were not enough points in any stratum to detect a significant difference (not enough plots). In order to provide a general set of equations we kept the dichotomy (≤ 45 cm and > 45 cm) for all species. The lower strata of the 3D-quadrat can also be used to estimate grass layer abundance and tree regeneration.

Table 1 Parameter estimates for relationships between leaf biomass and number of touches with linear regression for the different species

Species	Length (cm)	Equation	R^2	n
*Acer*spp.	0–45	0.459 + 0.137 *X*	0.41	22
	45.1–165	0.627 + 0.111 *X*	0.30	31
Others[a] and *Euphorbia* spp.	0–85	0.232 + 0.113 *X*	0.34	44
Carpinus betulus and *Ulmus minor*	0–45	0.241 + 0.223 *X*	0.41	24
	45.1–165	0.549 + 0.154 *X*	0.47	42
Cornus spp.	0–45	0.342 + 0.262 *X*	0.84	7
	45.1–165	0.553 + 0.166 *X*	0.76	21
Corylus avellana,*Fagus sylvatica*and *Viburnum spp.*	0–45	0.742 + 0.190 *X*	0.35	13
	45.1–165	0.697 + 0.110 *X*	0.41	19
Crataegus spp., *Prunus* spp., *Fraxinus* spp., *Sorbus* spp. and *Rosa* spp.	0–45	0.442 + 0.169 *X*	0.37	43
	45.1–165	0.455 + 0.112 *X*	0.30	96
Evonymus europeaus,*Ligustrum vulgare*and *Lonicera periclymenum*	0–45	0.297 + 0.174 *X*	0.36	26
	45.1–165	0.329 + 0.128 *X*	0.45	18
Graminoides	0–45	0.389 + 0.105 *X*	0.61	64
	45.1–165	0.130 + 0.153 *X*	0.89	17
Hedera helix and *Tamus communis*	0–165	0.651 + 0.228 *X*	0.50	88
Ilex aquifolium	0–85	0.549 + 0.370 *X*	0.46	9
Quercus spp.	0–45	−0.061 + 0.247 *X*	0.61	27
	45.1–165	0.395 + 0.187 *X*	0.60	19
Rubia peregrina	0–85	0.312 + 0.275 *X*	0.42	39
Rubus spp. and *Ruscus aculeatus*	0–45	1.016 + 0.186 *X*	0.32	58
	45.1–165	0.996 + 0.143 *X*	0.30	57
Hyacinthoide	0–45	0.328 + 0.124 *X*	0.70	10

[a] *Ajuga reptans, Anemona nemorosa, Anemona sylvestris, Buglossoides purpurocaerulea, Clematis vitalba, Fragaria vesca, Fragaria viridis, Geum urbanum, Glechoma, Hypericum, Lapsana communis, Lathyrus niger, Mentha aquatica, Ornithogalum pyrenaicum, Veronica officinalis, Viola* spp.

Table 2 Parameter estimates for relationships between leaf biomass and number of touches with linear regression for three new species

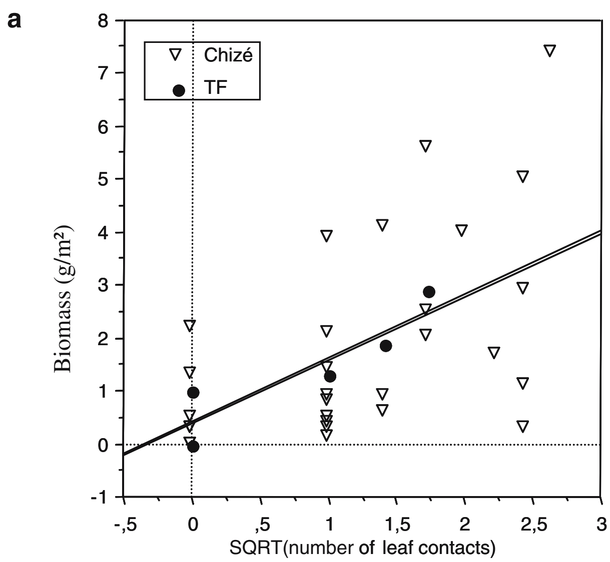
Species	Length	Equation	R^2	*n*
*Betula*spp.	0–45	0.386 + 1.540 *X*	0.74	24
	45.1–165	1.062 + 1.501 *X*	0.4	92
Populus tremula	0–45	−0.277 + 2.525 *X*	0.60	18
	45.1–165	1.155 + 1.764 *X*	0.33	79
Salix spp.	0–45	0.475 + 1.932 *X*	0.53	21
	45.1–165	0.496 + 2.768 *X*	0.56	77

The relationships between the number of leaf contacts and biomass suggest that our 'hit' index gives a reasonable estimate of leaf biomass for many species (Table 1), despite the fact that there is a large variability in the number of leaf contacts. The estimates given by our method will approximate the annual production of leaf biomass available to browsers because the data for the models were collected in spring (May and June) when leaf growth was complete or nearly complete (Ohmann et al. 1974). Moreover, in this study, the plants were essentially unbrowsed due to very low density of browsers in Chizé reserve (7.7 roe deer > 1 year of age/100 ha) for the 5 years before the study.

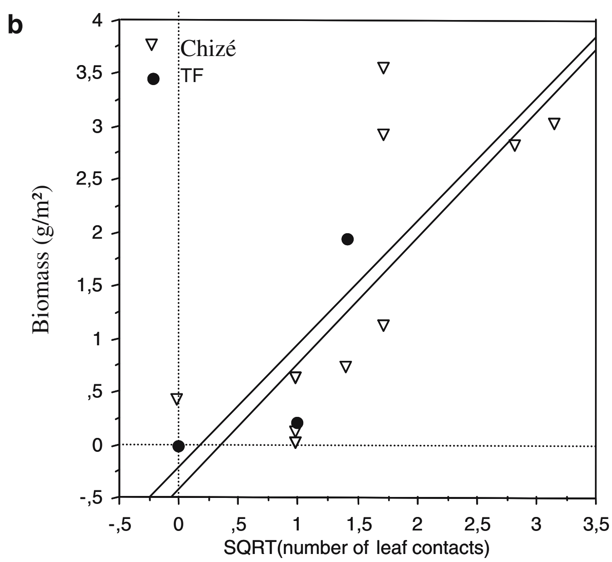
Assessing the usefulness of the equation on a sample plot in estimating the biomass reveals a difficulty common to all methods for estimating biomass.

The usefulness of any predictive equation to assess biomass in a given plot depends on how much variation

Fig. 2 Relationships between (**a**) biomass of *Rubus* spp. (0–45 cm) or (**b**) *Acer* spp. (0–45 cm) and square root of number of leaf contact for two sites (Chizé Reserve and Trois-Fontaines forest)



Biomass = 0.38 + 1.20 * SQRT(number of leaf contacts); R^2 = 0.31 (Chizé)
Biomass = 0.41 + 1.21 * SQRT(number of leaf contacts); R^2 = 0.82 (TF)



Biomass = -0.42 + 1.18 * SQRT(number of leaf contacts); R^2 = 0.58 (Chizé)
Biomass = -0.22 + 1.16 * SQRT(number of leaf contacts); R^2 = 0.63 (TF)

exists around the regression line. In the majority of cases the data from plot samples were highly variable, hence a large variance. Consequently, a large number of plots are necessary to limit the effect of background noise on the construction of the equations relating the dried biomass to the number of contacts per species. The relationship between the biomass of vegetation and the number of contacts for a given plot also depends on the period when the vegetation was clipped for the calibration. In our case, the calibration was done during May and June, which corresponds to the peak biomass production period. This implies that our biomass values for any given number of contacts are fairly representative of the potential leaf standing crop, but will be high compared to values obtained early in the growing seasons, when leaves have not reach their final size. This suggests that equations may need to be adjusted for some specific seasons. Table 1 shows that using a number of contacts as an index of biomass is justified when the form of the leaf is not complex (ex: *Cornus* spp. and *Quercus* spp.). As with most methods based on clipping and weighing, once the equations are built, it is very practical to use only the index to assess forage availability and habitat quality, hence saving time and energy. As with any other method, calibration takes the longest time which took an average of 1h per 3D-quadrat sampling frame for species composition, counting 'hits', clipping, drying, and weighing. Once the calibration is done, assessment of species composition and counting 'hits' only require 5–10 min per 3D-quadrat for one person. Our method is also designed to provide information about biomass availability in different height strata. The most significant added value of our method is that it is based on a 3D index of biomass (the number of contacts on the five rods are associated with the leaf biomass content in the volume defined by these rods), in contrast to the standard methods that use a linear index (number of contacts on one single rod). We feel that it is therefore more realistic given the many shapes and spatial distribution of branches and leaves in browse species. In general, this type of index will be better adapted to patches of resources that are heterogeneous in structure.

Comparing the two sites we found a similar slope for each species and the same intercept (t-test, $P > 0.2$ for each species) (Fig. 2). In fact, it appears that the higher soil moisture in Trois-Fontaines compared to Chizé caused a difference in biomass per branch and vegetation structure, but this did not change the relationships, because it affected primarily the number of hits but not the weights of leaves. Consequently, it may be necessary to perform some more tests on our biomass index, in different sites, but we think that our equations can be readily applicable in temperate deciduous forests. In addition, we found that this method was easily mastered by workers with limited experience in botany and was repeatable. This method will help land-managers to integrate habitat information into management plans, both of animals and their resources.

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